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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

No. 212

WOOD VERSUS METAL IN AIRPLANE CONSTRUCTION.

By H. Seehase.

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WOOD VERSUS METAL IN AIRPLANE CONSTRUCTION.*

By H. Seehase.

In the construction of important parts of aircraft, both metal and wood, as well as a combination of the two have been used. Unfortunately, the use of "Wood or Metal" has often been determined by prejudice in favor of the one or the other known type, and this method of settling the matter is likely to hamper in no small degree the further development of aircraft construction. The aim of this article is to present, in broad outline, a scientific method for solving the problem, "Wood or Metal." It will also be shown that structural methods have by no means reached their final perfection, but are still capable of great improvement.

In order to decide on the merits of the various methods of construction, it is necessary to know the strength of the material used. The Theory of the Strength of Materials gives certain characteristics referred to a given unit of area, as, for instance, 45 kg/mm^2 (64000 lb/in^2), for the ultimate tensile strength of soft steel. In comparing these figures, test bars of like cross-section and length are therefore assumed, the weights of which differ greatly, according to their specific gravity. In order to take into account the influence of specific gravity, we have divided the strength by the specific gravity, thus obtaining the modulus of rupture. These derived characteristics are of little value in judging the worth of

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construction materials, since they only apply to a certain degree of loading. We may get a clear idea of the strength of materials in relation to specific gravity by tracing a graph showing the numerical characteristics of rods of equal weight and length. These rods are of pine, duralumin, cast iron, and soft steel. A cross-section of each is shown in Fig. 1. The heavy lines to the right of the cross-sections indicate their relative areas, and bring out the differences between them more clearly, thus showing the superiority of lightweight materials for parts subjected to heavy local stresses.

The elongation diagrams of these rods of equal weight are shown in Fig. 2. The two values given for the wooden rod (20 mm in diameter by 200 mm in length) ($.79 \times 7.87$ in.), are for selected, first-quality pine. The elongation of the metal rods was computed for a length of 200 mm (7.87 in.), taking into account the ratio of diameter to length. These diagrams show clearly and at a glance the reaction of construction materials to any degree of stress. This method holds many surprises for those accustomed to computing with the figures given by the Theory of the Strength of Materials. A wooden rod for instance, is five times as strong as one of soft steel and ten times as strong as one of cast iron. Even the best hard-drawn steel with a strength of 220 kg/mm^2 (313000 lb/in^2) (tension wire) does not attain the strength of the wooden rod. The extreme limits of the different kinds of steel are given by Steel 1, of high ductility, and Steel 5, a special steel worked up to the condition of greatest strength.

Duralumin comes within these limits. In the form in which it is

used for tubes, etc. it has considerable strength and ductility. Its ductility is much increased by annealing,* while its strength remains about the same. Duralumin differs greatly therefore from steel, the ductility of which is always reduced by tempering. While these phenomena have been thoroughly investigated in steel and are well known in all steel plants, they have not yet been sufficiently investigated in duralumin. If a simple and uniform method of annealing duralumin should be discovered and one could count on the result being permanent, this metal would rapidly come into use for parts subject to high stresses.

In Fig. 2 we also see that rods made of material having, according to the Theory of Strength of Materials, a high modulus of elasticity ($\alpha = \frac{1}{E}$, wood $\frac{1}{2,200,000}$, duralumin $\frac{1}{10,000,000}$, steel $\frac{1}{30,000,000}$), give surprisingly small elongations. The elongations under a load of 520 kg (1146 lb) are shown in Fig. 3. The wooden rod W1 has less elongation than the metal rods, while rod W2 has more. The rods of the same weight, which are here examined, give approximately the same elongation for the same load.

In compression tests also it is very instructive to compare test rods of the same weight. In Fig. 4, the curves of pressure and elongation are given only for such materials as behave differently under tensile and compression stresses. The elongation curves of Fig. 2, are also drawn in Fig. 4, for facility of comparison. A comparison of these bodies having tensile and pressure stresses proportional to their cross-sections can, however, only be carried to the limit of compression. For the elongation, a larger unit of measure was chosen for the sake of clearness. The test specimens here used have the

* Technische Berichte, Vol. III, No. 6, gives no definite data on the ratio of length to cross-section. $l = 11.3\sqrt{f}$ is assumed.

same cross-sections as the ones in Fig. 2, their length being 20 mm (.79 in.).

The line drawn under the above elongation diagrams corresponds to the force expended in changing the shape. In Fig. 5, this is shown for the tensile tests of each of the rods of equal weight. The previously considered tensile and elongation curves and the potential power only hold good, however, for relatively small rates of deformation, such as are usually employed in laboratory strength tests. With sudden stresses, such as occur under actual working conditions, other values will be found. In one of my previous papers* details were given on the determination of diagrams of pressure and elongation and the force required for the alteration of form under impact. With an impact of the duration of 0.0015 second, for instance, the power absorbed for soft steel was 24% more than in an impact lasting 1200 seconds. For brass, the stress was lower under impact than in slow deformation. With this alloy, the power of resistance also diminished with increased rapidity of stress. The potential energy indicated in Fig. 5 for duralumin (especially if annealed) will probably be smaller in dynamic stresses.

For a more accurate judgment concerning material to be used in highly stressed airplane parts, we must also know its power of resistance under static and dynamic impact. Such discussion is outside the limits of this paper. For the furtherance of airplane construction, scientific research on the still obscure problem of the

* H. Seehase: "Experimental analyses of impact and the determination of deformation work in impact tests," in Forschungsarbeiten des Vereins deutscher Ingenieure, No. 182.

effects of impact on bodies of equal weight is urgently needed.

In order to obtain the material most suitable for a given problem in construction, it must be chosen in accordance with the principles indicated above. The success of the construction, be it metal or wood, depends largely on whether the material has been properly prepared, in view of its special properties and of the strength required. Some wooden airplanes get rapidly out of shape under the influence of dampness, while others are scarcely affected.

Highly stressed metal parts may easily fail under the stress of forces variously applied, if such forces exceed a certain limit, even though this limit be far below that obtained in static tests. These stress limits are usually ascertained by means of a single calculation of the theory of strength which does not take into account the temporary extension of the engendered pressures.. Pressure in any material spreads with the velocity of sound peculiar to that material. Hence the reaction arising from change of cross-section may cause a doubling of the tension. Also, supplementary forces not previously calculated may arise in consequence of the phenomena of resonance and, since the bending oscillations due to resonance cause great change of form, they are easily recognized and eliminated. There are, however, similar vibrations due to tensile, pressure, and torsion stresses, which do not cause any great change in shape.

It is known that variation of engine power, if coinciding with the natural vibration of any structural member of the airplane, (strut, spar section, or the whole wing), will give rise to such

disturbances. Since we can make no great change in the revolution speed of the engine, nor in the direction of pressure, vibrations due to resonance can only be eliminated by structural modifications. Wood seems to be least affected by these harmful vibrations, while metal is much more sensitive to them. According to experiments thus far made, very ductile steels are better in this respect than high resistance steels.

In choosing the material for construction, the facility of repairs must be considered. It will certainly be an advantage, if material for repairs can be found anywhere and if airplanes are so constructed that they can be quickly and efficiently repaired on the spot by ordinary methods.

The foregoing discussion was intended to show how to get an objective conception of the problem of wood or metal airplane construction. Important differences between the materials have been discussed from new points of view. It is, of course, impossible to deal exhaustively with these methods of research within the limits of this paper, further research work being necessary, in order to extend and complete them. This cursory comparison may also have shown that the methods of construction hitherto employed are capable of improvement. In this connection, I will describe a new method of steel construction tried out by the Sablatnig Aircraft Construction Company, of Berlin. A characteristic property of steel is that its strength is considerably increased by cold treatment (rolling, drawing, and hammering). Hard-drawn, seamless steel tubes

have a strength of about 50 kg/mm^2 (71000 lb/in^2). This drops to about 27 kg (59.5 lb) - a loss of 46% - if the tube is subjected to great heat as, for instance, in autogenous welding. Hitherto, in aircraft construction, we have had to make the best of this drawback, since riveting is too complicated and is, moreover, unsuitable for some of the parts. The harmful effect of heat in joining structural parts can, however, be avoided. Fig. 6 shows a tube welded by the new method. The ends of the tube are cut obliquely and the joint is bridged over by a plate of sheet metal which is also cut diagonally, the sloping edge running parallel to the slope of the joint, and extending into it a short distance. The plate and tube are welded in the usual way, and the parts of the tube which do not need to come into contact with the flame are effectually protected by a shield. Fig. 7 shows how this is done. When the welding is completed, we see that the characteristic color of tempering (indicated by cross-hatch lines on the figure) extends only a very little distance on either side of the weld, showing that the protection was effective. Its color indicates the temperature. If we now examine the cross-sections shown in Fig. 6, we shall see that some parts of the wall of the tube have been annealed, while other parts still have the original degree of hardness imparted to them by cold treatment. The annealed parts are shown by hatching, while the parts unaffected by the heat, are shown in black. Since the heated zone is confined to the immediate vicinity of the weld and the joint is strengthened by the strip of sheet metal, the strength of the tube is practically unimpaired. The very small annealed zone of

cross-section 2 (at the end of the joint), which is not reinforced, is reduced to a minimum in comparison with the unannealed part. The welded portions therefore consist of well-annealed, tough steel of high ductility, which gradually increases in strength, as the annealed part is traversed, to the value of the cold-treated steel. All the objections formerly urged against this sort of welding are thus eliminated, so that it is now possible to weld highly stressed steel parts without lessening their original strength and all the various forms of joints can be used which make for light weight. The parts manufactured in this way are the same as though cast in a single piece. This method of construction has been described here as applied to the welding of tubes of equal diameter, but it can be extended, as required, to other structural problems.

In order to thoroughly test out this method of construction, a special experimental airplane was built in which all the important parts (fuselage, landing gear, spars of the cantilever wings and tail planes) were made by the method above described. This small airplane is shown in Fig. 8. It is equipped with a 50 HP Siemens engine, is a two-seater, and can carry fuel for a flight of five hours. Its speed is 125 km/h (77.67 M.P.H.).

The wing has two spars made of welded steel tubing, the ribs being made of duralumin tubing. The joints are welded as shown in Fig. 6, the ribs being joined to the spars as shown in Fig. 9. The end of each cross-rib is flattened and welded to the spar, both sides of the weld being protected by a piece of sheet metal. The parts affected by the heat are distinguished from the hard parts, as

in Fig. 6. Fig. 10 gives a view of the semi-spar. Its aspect ratio (depth : half length) is 1 : 18.5. The two following figures show the joints of the fuselage modified by the new method of construction. In Fig. 11 is shown a solid forged connecting piece welded to radiating tubes. Fig. 12 shows a longeron, passing unweakened through a joint and welded to the angle tubes by means of a longitudinal sleeve. The sleeve has here the effect of reinforcing the cross-section in place of a joint-plate.

The retention of the strength at a joint is of great importance, for a very slight deflection at this point (which was unavoidable with the old method of welding) has caused premature failure of the longeron. The method of bracing with turnbuckles and eyelets is very liable to cause a breakdown. Under the heavy bending stresses occurring in curved flight such eyelets are liable to give way. This disadvantage is avoided by the new method of bracing shown in Fig. 13, which eliminates the harmful bending stresses. This device is much lighter and about half the length of the bracing device formerly used. The nipples are of the standardized type used in automobile construction.

The fuselage and wings of this airplane were subjected to breaking tests in the usual way. The longeron of the fuselage with its relatively great length, yielded uniformly throughout its whole length, instead of breaking within a single compression bay as usually happens, thus proving its strength to be unimpaired by the joints.



Under the pressure of the breaking load, the tubes forming the wing spars gave way near the points of assemblage. The calculated breaking load was 50 kg/mm². A section of equal length and diameter taken from the tube near the point of rupture and tested, gave a strength of 51 kg/mm² (71000 lb/in²). This slight difference of 2% lies within the limits of error. A similar tube, annealed, had a strength of only 30 kg/mm² (42670 lb/in²). It is therefore proved that airplane parts subject to heavy stresses can be made by autogenous welding without fear of their strength being impaired by the heat. Since tubes of hard-drawn steel have a strength of 51 kg/mm² (72540 lb/in²) (68% higher than those of annealed steel, 30 kg/mm²), much weight can be saved.

After the breaking test, the airplane was rebuilt. The ruptured parts were replaced by welding and others by the method just described. Although a considerable amount of repairing had to be done, it was all accomplished very rapidly and easily. The possibility of carrying out repairs easily and without the complicated machinery of a large factory would be of great advantage to air traffic.

Translated by Paris Office,
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Figs. 1, 2, 3.

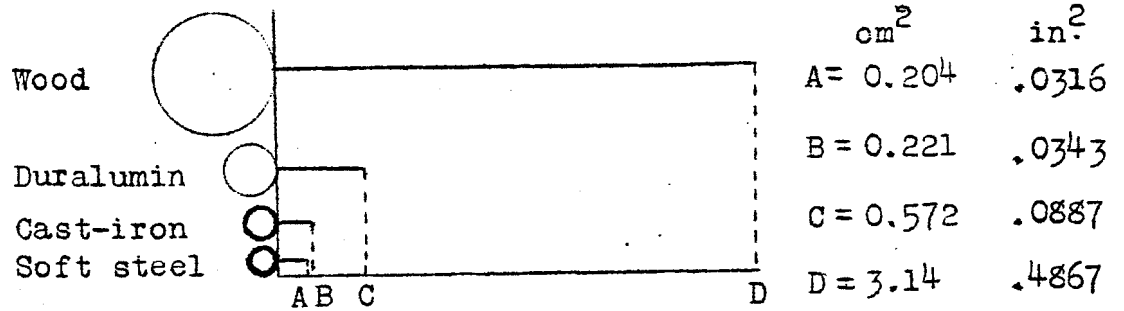


Fig. 1.

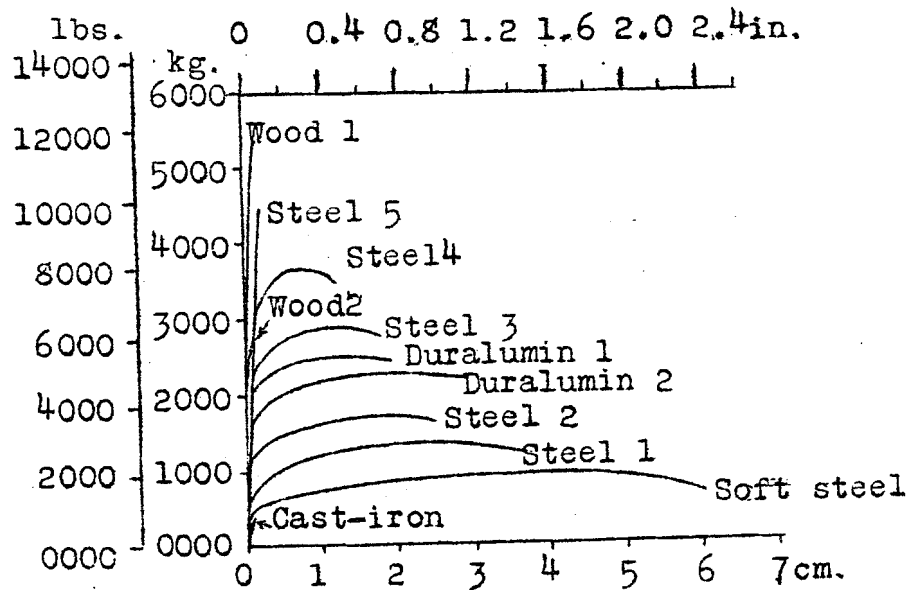


Fig. 2.

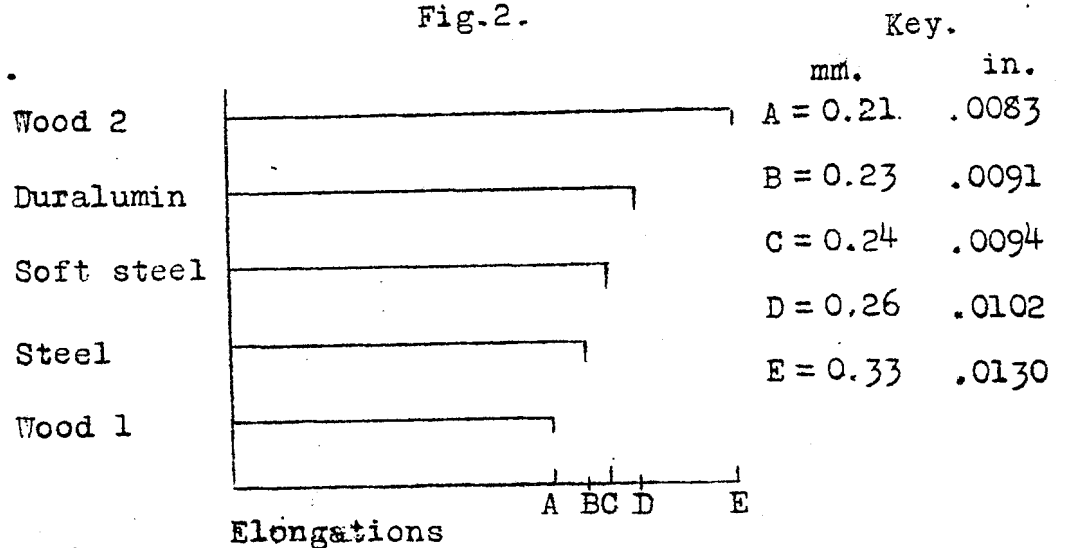


Fig. 3.

Figs. 4, 5, 6,

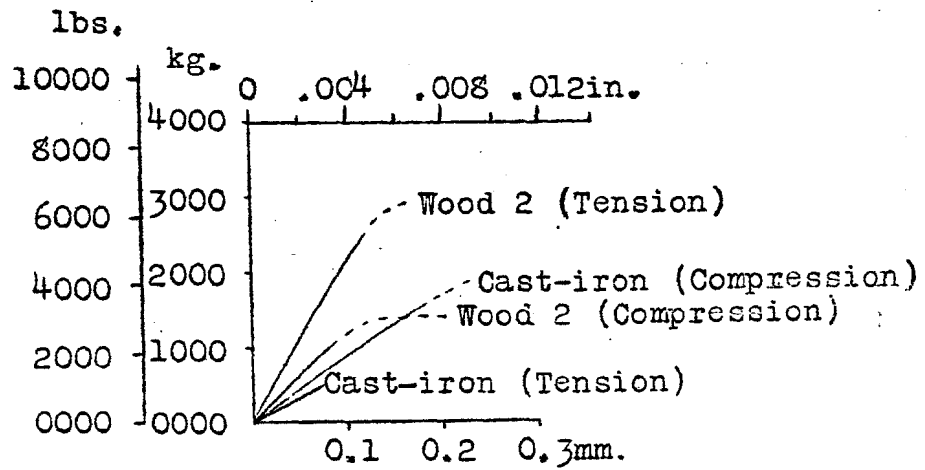


Fig. 4.

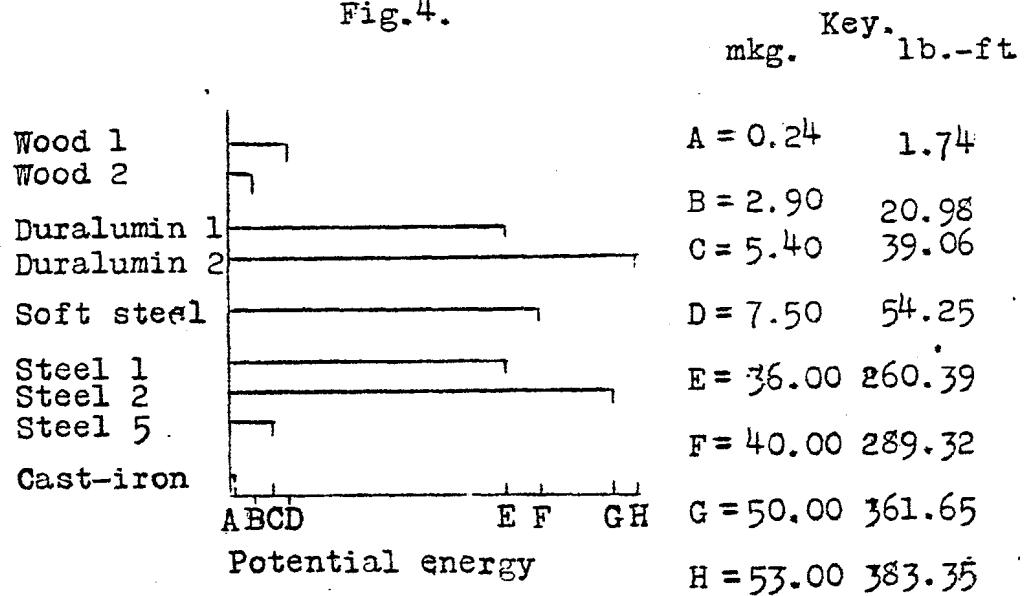


Fig. 5.

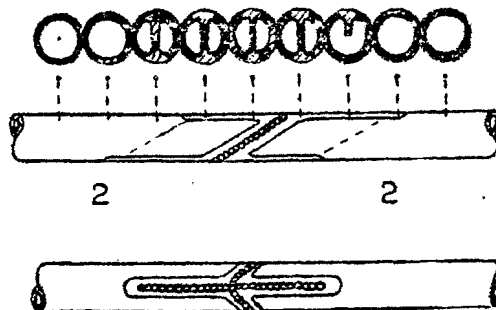


Fig. 6.

Figs. 7, 8, 9.

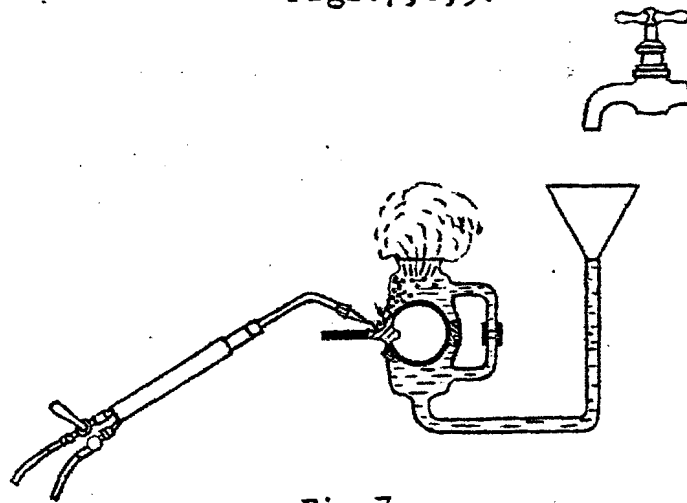


Fig. 7.

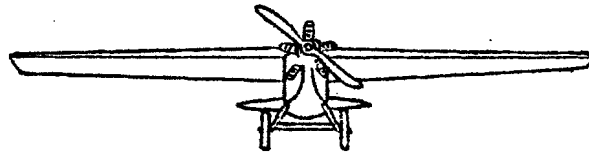
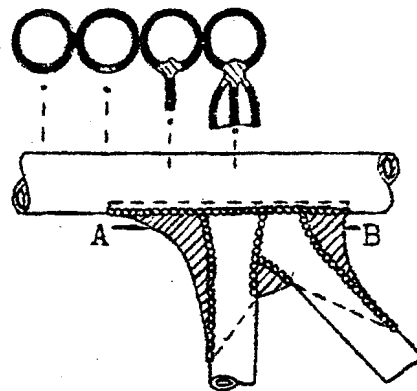


Fig. 8.



Section A-B



Fig. 9.

Figs. 10, 11, 12, 13.

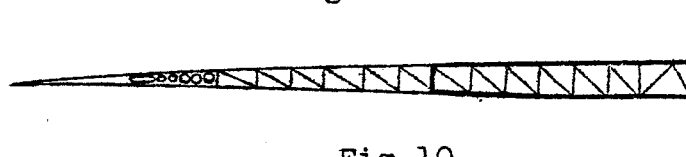


Fig. 10.

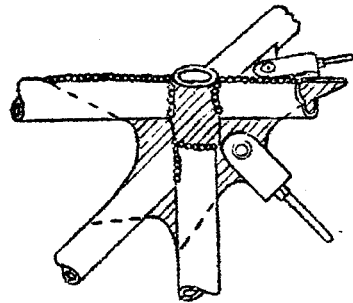


Fig. 11.

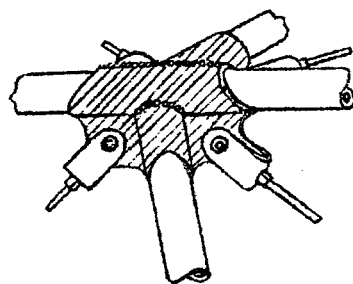


Fig. 12.

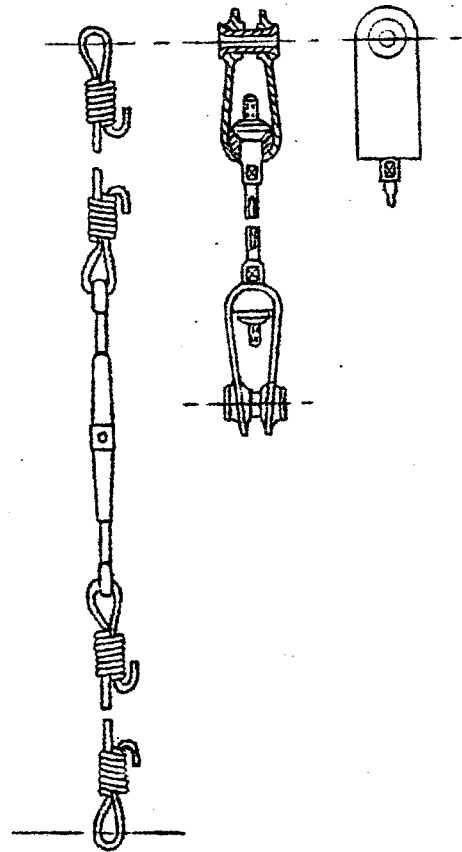


Fig. 13.